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Decomposition of birch leaves: dry weight loss, chemical changes, and effects of artificial acid rain

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With 3 figures

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1. Introduction

During the last decades, the acidity of rain and snow has increased markedly over large parts of Europe. Acidified precipitation in Scandinavia is mainly due to long-range transported industrial air pollutants from middle Europe (Dovland et al. 1976, Oecd 1977). Corresponding problems are found in North America (Likens et al. 1979).

Forest growth depends to a large degree on the release of nutrients by decomposition processes in the soil. During the last few years, interest has increased in possible effects of acidification on decomposition rates and soil chemistry. Strong artificial acidification with diluted sulphuric acid has resulted in reduced decomposition rates of raw humus (Tamm et al. 1977, Hågvar & Abrahamsen 1980), of root and needle litter from Scots pine (*Pinus sylvestris* L.) (Bååth et al. 1980), and of needle litter from Norway spruce [*Picea abies* (L.) Karst.; Hovland et al. 1980]. Increased leaching of several metal cations has also been observed from needle litter (Hovland et al. 1980), as well as from raw humus (Hågvar & Abrahamsen 1980, Abrahamsen 1980a), and from mineral soil (Abrahamsen 1980a). The present investigation adds a new litter type to these studies, namely deciduous leaves. Decomposition rate and chemical properties of birch leaves were studied under various degrees of artificial acidification, and under both field and laboratory conditions.

A part of this material was included in a thesis at the University of Oslo (Kjøndal 1980).

2. Material and methods

2.1. Field experiment

The field experiment was carried out on a clear-cut area in a forest consisting mainly of Norway spruce and Scots pine. The site was located on a flat plain of glacifluvial sandy deposits about 40 km north of Oslo. The soil was a podzol (Typic Udipsamment, USDA classification), with an organic (O) and a bleached (Ae) horizon each about 3 cm thick. The vegetation type was Eu-Piceetum Myrtilletosum, with *Deschampsia flexuosa* (L.) Trin. as a dominant plant. More details of the experimental area (named A-3) are given by Abrahamsen et al. (1976a) and Stuanes & Sveistrup (1979).

Each experimental plot (4 × 4 m) contained 36 small birches (*Betula verrucosa* Ehrh.) planted in 1974, a half year after the clear-cutting. A supplement planting had to be carried out one year later. At the end of the experiment in 1978, the birches measured 1.1 m in average. The experiment was designed as a block experiment with four replications. The treatments included unwatered plots and plots supplied with artificial "rain" with the *p*H values of 6, 4, 3 and 2. Fifty mm artificial "rain" was applied monthly from May to September, using ground water (with a mean *p*H of 6) plus controlled amounts of sulphuric acid. Because natural precipitation came in addition, the weighted annual mean *p*H of the treatments were 4.5, 4.2, 3.4 and 2.5, respectively. The watering started in June 1974. Details of the experimental design and watering equipment are given by Abrahamsen et al. (1976a).

Cylindrical litter bags with a mesh size of 1 mm, 3 cm high and with a diam. of 6.5 cm, were each filled with 6.85 g (dry weight) of birch leaves which had been collected during leaf fall the previous year. As the leaves came from two species (*B. verrucosa* and *B. pubescens* Ehrh. in a ratio of approximately 1 : 2) and also varied in size, the whole material was thoroughly mixed before use. The leaves were moistened to faciliate the filling of the bags. As the same samples were also used later for microarthropod studies, the leaves were mainly packed vertically. The animals would then be able to emigrate from the samples during extraction. At 28 July 1975, the bags were placed into the 0-layer, so that the upper surface was at the same level as the litter surface. Dates for the four samplings and the number of litter bags sampled each time are shown in Table 1. It should be noticed that the sampling in autumn 1975 was made only one month before a permanent snow cover was formed, and the spring sampling in 1976 just when the last snow melted away.

Monthly precipitation and mean temperatures during 1975—1978 are shown in Fig. 1, together with standard normals.

Chemical analysis of the leaves were performed according to Ogner et al. (1975, 1977). *p*H values of dried, ground leaves were measured in distilled water at a volume ratio leaves: water of 1 : 2.5.

2.2. Laboratory experiment

The field experiment was originally designed to study the effect of acidification on tree growth and soil chemistry. There were some weak points in the studies on litter decomposition: the artificial acid "rain" was applied only five times a year (monthly from May to September), and the "rain" was not so evenly distributed on the ground as could have been desired. Furthermore, natural rain came in addition to the acidified water. It was therefore decided to supplement the field studies with a more controlled laboratory experiment. This was performed in a greenhouse during a three-month period, from November 1977 to February 1978.

For this purpose, a smaller cylindrical litter bag type was used: 3 cm high, 3.4 cm in diam. and with a mesh size of 0.6 mm. There were two categories of leaves: one group which had not undergone any decomposition after leaf fall, and another group which had already lost about 40 % of the dry weight. The effect of acid "rain" on the early phase of decomposition was studied in the first group. The other group was used to illuminate the effect of acid "rain" at an advanced state of decay. The latter bags had previously been situated for 6 months in a greenhouse, placed into the 0 layer of a weakly-developed podzolic forest soil from a plant community corresponding to the field experiment.

Bags with leaves in a late phase of decomposition were divided into three groups of twelve bags each, and were given artificial "rain" of *p*H 5.3, 3, and 2, respectively. Bags with "fresh" leaves were divided into four groups of fifteen bags each, and were given "rain" of *p*H 5.3, 4, 3 and 2. The salt content was adjusted so that it resembled that of natural rain in southernmost Norway (values in mg l^{-1} were: Ca^{2+} 0.24, Mg^{2+} 0.18, K^{+} 0.12, Na^{+} 1.29, NH_4^{+} 0.54, NO_3^{-} 1.86, Cl^{-} 2.73, SO_4^{2-} 0.39).

Table 1. Number of litter bags "harvested" at each sampling, distributed on five treatments and four replications. The *p*H values of the artificial "rain" are given on the top of the table

Treatment		Not watered	*p*H 6	*p*H 4	*p*H 3	*p*H 2	
Replication no.		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
Sampling	Date						Total
I	19. 9. 1975	2 2 2 2	2 2 2 2	2 2 2 2	2 2 2 2	2 2 2 2	**40**
II	28. 4. 1976	4 4 5 4	5 6 3 3	5 5 4 3	4 5 3 5	5 6 3 3	**85**
III	2.—9. 11. 1976	8 8 8 8	8 8 8 8	8 8 8 8	8 8 8 8	8 8 8 8	**160**
IV	10. 11. 1978	5 5 5 5	6 6 4 4	5 5 4 5	6 6 3 4	5 6 5 2	**96**

Note: Litter bags were laid out 28. 7. 1975.

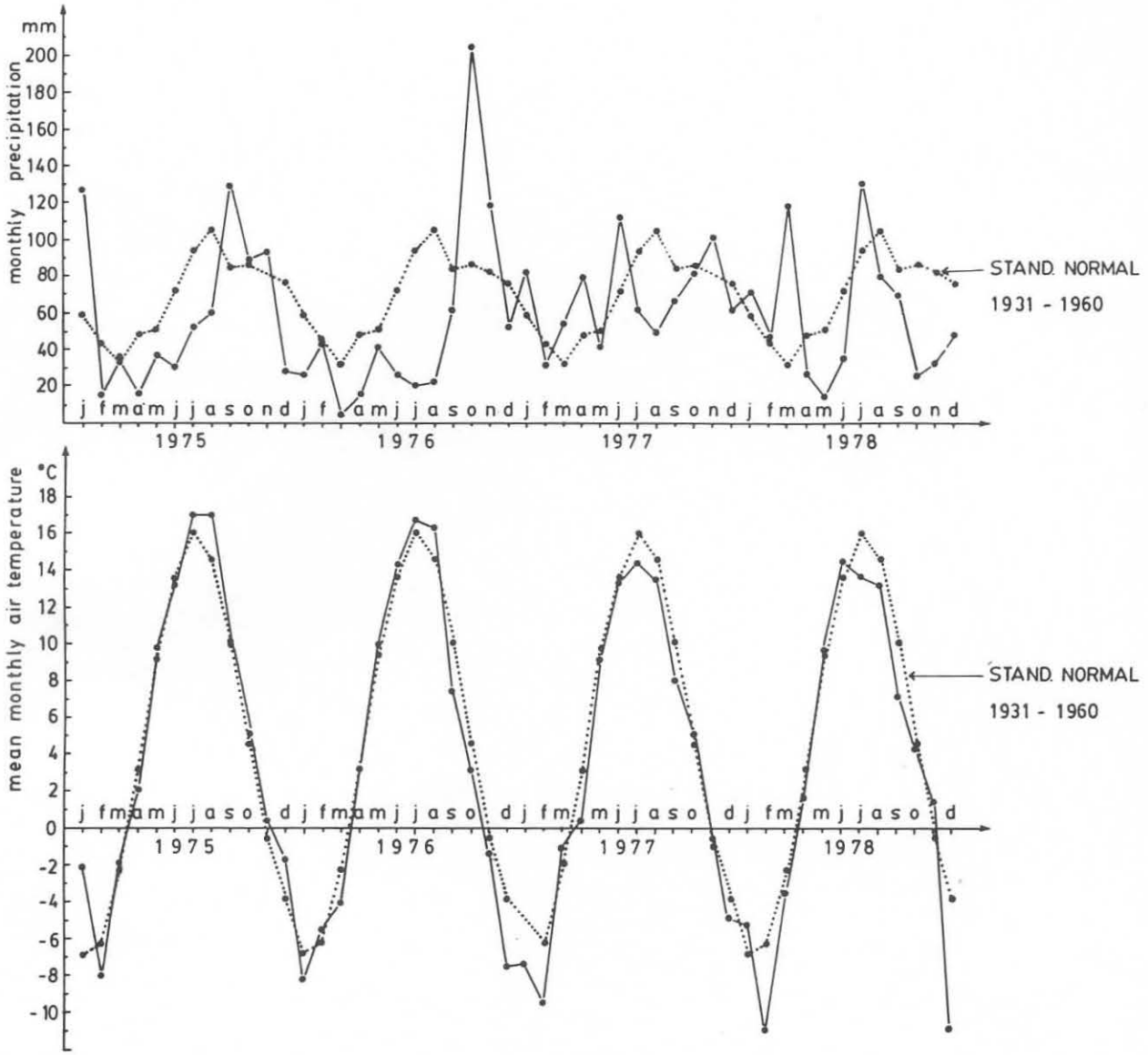


Fig. 1. Monthly precipitation and mean air temperature at a neighbouring weather station (Gardermoen) during the experimental period, together with standard normals.

Litter bags receiving unacidified water (pH 5.3) were considered controls, while the other pH levels were achieved by adding sulphuric acid. Before the treatments started, all bags were put into the 0 layer of forest soil so that the upper surface of the bag was at the same level as the litter surface. The soil, of the same type as mentioned above, was kept in drained plastic containers ($60 \times 40 \times 10$ cm). To minimize variation in soil properties between containers, each was filled up with twelve or fifteen small soil blocks which had been dug out at random in the forest and carefully put together. Each small block contained one litter bag. Thus, all bags with leaves in the same stage of decomposition and receiving "rain" of the same pH level, were in the same container.

Twice every week, each container with soil and litter bags received 10 mm of "rain", which corresponds closely to the natural precipitation in the area. During the experimental period, the air temperature remained mostly between 15 and 25 °C. Before sampling, all containers were watered with 10 mm of distilled water, to wash out remainder of free acid from the litter.

3. Results

3.1. Decomposition rate

3.1.1. Effect of season and decomposition phase

3.1.1.1. Field experiment

The decomposition rate of unwatered samples is illustrated by the black columns in Figure 2. During the first seven weeks the mean weight loss was 10 % (sampling I). A considerable weight loss occurred in the next period, when the ground was mostly covered by snow,

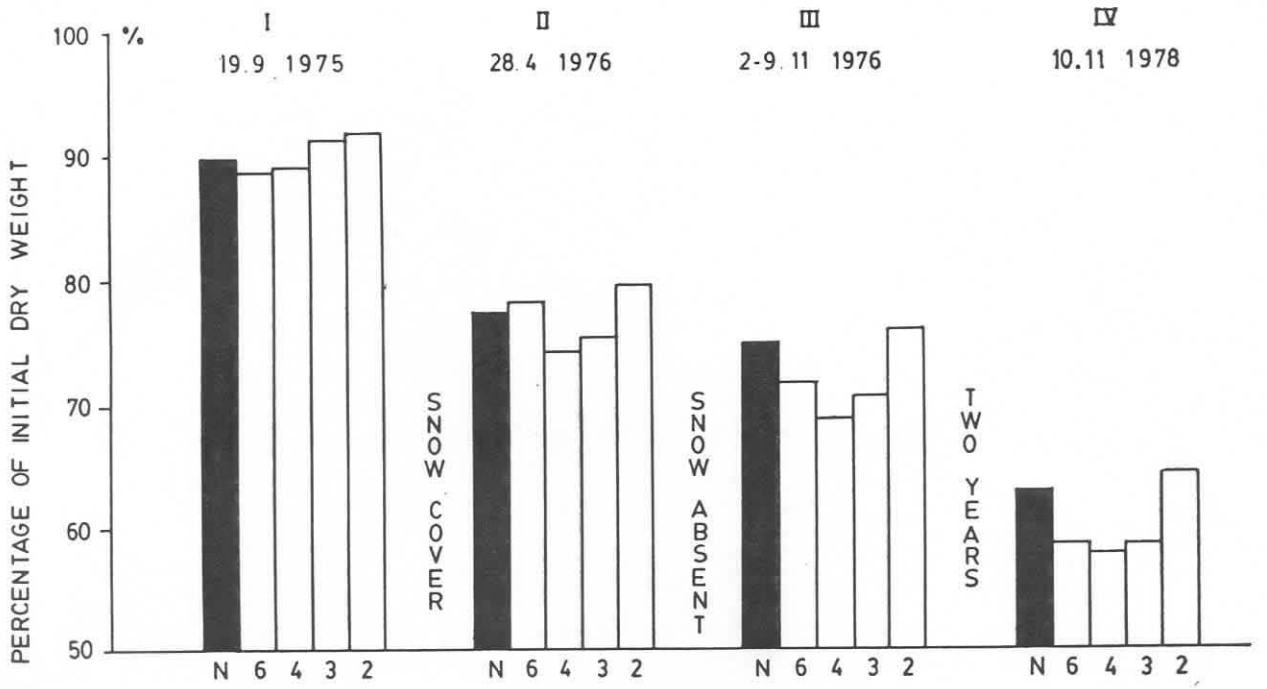


Fig. 2. Dry weight reduction of birch leaves in litter bags (laid out 28. 7. 1975). Black columns: Non-watered plots. Figures at the bottom indicate *p*H in artificial rain.

leaving 77 % of the original dry weight at snow melt 1976. During the following spring, summer and autumn, dry weight loss was only 2.5 % (sampling III). Two successive years only reduced the weight by an additional 12 %, so that 63 % on average was still left in the bags.

3.1.1.2. Laboratory experiment

Decomposition was considerably faster under greenhouse conditions than in the field. "Fresh" leaves treated with "rain" of *p*H 5.3 for three months were reduced to the same dry weight level as after three years in the field (to about 63 % of the original dry weight, Table 2). The decomposition rate of "late phase" leaves was slower, being reduced from the initial 59 % to 44 %.

3.1.2. Effect of acidification

3.1.2.1. Field experiment

Among the watered bags (open columns in Figure 2), the strongest acidification (*p*H 2) gave the highest dry weight values in all four samplings, indicating a slower decomposition rate. Except at the third sampling, however, differences between treatments were not significant by analysis of variance. At this sampling, dry weights at *p*H 2-treated plots were significantly higher than at *p*H 3-treated plots ($P < 0.05$) and *p*H 4-treated plots ($P < 0.01$), and the difference from control-watered plots was close to significance (Figure 2).

3.1.2.2. Laboratory experiment

In both the early and late decomposition phase, the strongest acidification gave the slowest mean decomposition rate (Table 2). However, the difference between *p*H 2-treated bags and the other treatments was significant only in the early phase ($P < 0.01$).

3.2. Leaf chemistry

3.2.1. Effect of season and decomposition phase

3.2.1.1. Field experiment

Changes in leaf chemistry during decomposition in the field experiment are shown in Figure 3. Looking at the values from non-watered plots (black columns), K and P are the two elements which were most rapidly lost. Less than 20 % of K was left after the first autumn

Table 2. Effect of acidification on decomposition rate (dry weight) and chemical composition of birch leaves in early and late phase of decomposition (greenhouse experiment).

		% of initial weight							Elements: mg/100 g dry weight						
		A: Early phase				B: Late phase			A: Early phase				B: Late phase		
Start		pH 5.3	pH 4	pH 3	pH 2	pH 5.3	pH 3	pH 2	pH 5.3	pH 4	pH 3	pH 2	pH 5.3	pH 3	pH 2
Dry weight (g)	1) A: 1.79 2) B: 1.89	62.6	65.9	62.6	70.4	43.9	44.4	47.1	1.12 ± 0.11	1.18 ± 0.08	1.12 ± 0.06	1.26 ± 0.06	0.83 ± 0.13	0.84 ± 0.08	0.89 ± 0.13
Ca	1,428 ± 41.8	90.2	87.0	87.8	60.8	65.2	60.3	13.3	2,059	1,884	2,003	1,233	2,121	1,938	404
Mg	269 ± 8.1	78.1	77.1	68.8	30.8	44.4	34.7	6.8	336	315	296	118	272	210	39
Mn	101 ± 5.4	91.0	93.9	95.3	46.6	75.6	77.0	10.7	147	144	154	67	174	175	23
K	595 ± 31.6	20.5	18.2	16.5	18.1	8.9	8.2	5.7	195	164	157	153	121	110	72
N	1,338 ± 46.7	111.3	107.9	116.3	132.3	81.7	82.6	88.6	2,379	2,190	2,487	2,514	2,488	2,488	2,518
P	183 ± 5.8	61.1	54.7	55.3	73.0	35.5	30.6	27.8	179	152	162	190	148	126	108
S	123 ± 3.5	92.1	90.6	111.0	248.0	79.4	90.2	150.0	181	169	218	433	222	249	391
Mean pH of leaves	4.72								5.32	5.56	5.39	3.68	5.33	5.19	2.94

1) Freshly fallen leaves (early phase). 2) Mean weight was 59 % of that when acidification started (late phase).
Note: SD is given for dry weights (n = 12—15), and for elements at the starting point (n = 10). The pH of artificial "rain" is given in the head of the table.

Table 3. *p*H in decomposing birch leaves during a period of more than three years, including the effect of artificial acid rain (field experiment)

Treatment (*p*H in artificial rain)	Sampling I 19. 9. 1975	Sampling II 28. 4. 1976	Sampling III 2.—9. 11. 1976	Sampling IV 10. 11. 1978
Not watered	5.13 ± 0.13	5.20 ± 0.10	5.38 ± 0.18	5.24 ± 0.26
*p*H 6 (control)	4.94 ± 0.21	5.26 ± 0.17	5.46 ± 0.15	5.21 ± 0.14
*p*H 4	5.18 ± 0.28	5.29 ± 0.11	5.34 ± 0.14	5.09 ± 0.32
*p*H 3	5.01 ± 0.20	5.12 ± 0.07	[1])5.11 ± 0.15	4.98 ± 0.28
*p*H 2	4.96 ± 0.18	5.12 ± 0.18	[2])4.77 ± 0.07	[3])4.04 ± 0.12

1) Sign from control ($P < 0.01$). 2) Sign. from control ($P < 0.001$). 3) Sign. from control ($P < 0.001$). Note: Mean values ± SD are based on four replications. *p*H at the start (28. 7. 1975) was 4.72 ± 0.04.

and winter (sampling II). Ca and Mg were lost more gradually, Mg somewhat faster than Ca. The total amount of Mn and S in the decaying litter was not reduced after three years. The total amount of Mn seemed even to increase at the last sampling. The amount of N clearly increased during the last two years.

Measured as mg/100 g dry weight, N, Mn and S were gradually concentrated during the decomposition process. The concentration of Ca was slightly above the initial value during all samplings. Except for the last sampling, the Mg concentration remained unchanged. K and P had lowered but rather steady concentration during the last three samplings.

The *p*H of leaves on untreated plots was significantly raised from 4.7 to 5.1 during the first seven weeks ($P < 0.001$, Table 3). Later, *p*H did not change significantly over a three-year period. There was, however, a tendency for a temporary increase one year after the leaves were laid out (sampling III). This tendency was also apparent on plots given water of *p*H 6 and *p*H 4 (Table 3).

3.2.1.2. Laboratory experiment

In the control samples, there was a more rapid loss of K, and also of P, than of other elements (Table 2). Ca and Mg disappeared slower, but Mg somewhat faster than Ca. The amount of N increased during the "early" phase (which in dry weight loss corresponds to sampling IV in the field experiment), but was lowered in the later phase to values below that of fresh litter. Mn and S were retained to a level of more than 90 % during the first phase, but were then reduced to values below 80 %. These two elements were best retained next to N during both the "early" and "late" phases.

The elements were ranked in the same sequence in both the "early" and "late" phases, according to their loss in % of initial weight: K > P > Mg > Ca > Mn > S > N. This corresponds to the field results, except that Mn and S then changed places.

Quite parallel to the field experiment, the concentrations of N, Mn and S increased during decomposition. Likewise, Ca concentrations increased, but more markedly than in the field experiment. Mg concentrations first increased, but then returned to the original level in the "late" phase. K showed rather low values in both phases, while the concentration of P was not lowered until the "late" phase.

Also in the laboratory experiment, the *p*H of leaves increased during the early stages of decomposition and then was rather unchanged. The *p*H of distilled water-treated leaves both in "early" and "late" decomposition phase was about 5.3 (Table 2), which is 0.6 higher than the start value.

3.2.2. Effect of acidification

3.2.2.1. Field experiment

Ca, Mg and Mn were more effectively removed from the litter by increasing acidity in the "rain". This was evident both from the percentage of initial weight, and from the data on concentrations (Figure 3). N seemed to be strongest concentrated at the sites given "rain"

of pH 4, where also the mean decomposition rate was highest (Figure 2). At the third sampling, increased acidification gave larger amounts of P left, and also higher concentrations. This effect had, however, disappeared at the fourth sampling. Acidification did not significantly influence the amount of K and S in the litter.

The acid "rain" of pH 2 and 3 significantly reduced pH of the leaves (Table 3). After one year, leaves at the pH 2 treatment had pH values 0.7 units below the control, and after three years 1.2 units below.

3.2.2.2. Laboratory experiment

The most acid "rain" of pH 2 washed out much higher amounts of Ca, Mg and Mn than "rain" of other pH values (Table 2). This effect was most drastic in the later decomposition phase, where the Ca concentration was reduced to one fifth and that of Mg and Mn to one seventh of the control samples (pH 5.3). The concentration of N during decomposition was not influenced by acidification, but there was a tendency for increased total amounts being left after the strongest treatment. P and K seemed to achieve lower concentrations by increased acidification in the "late" phase, with lower total values also. In the present experiment, where natural rain was excluded, S from the acidified "rain" accumulated to roughly twice the normal value in the samples given water of pH 2.

The constant treatment with pH 2-water in the greenhouse reduced pH of the leaves even more drastically than in the field. The reduction was 1.6 pH units in the "early" phase and 2.4 units in the "late" phase (Table 2). No reduction in leaf pH was apparent from the pH 4- and pH 3-treatments (only mean values were measured, Table 2).

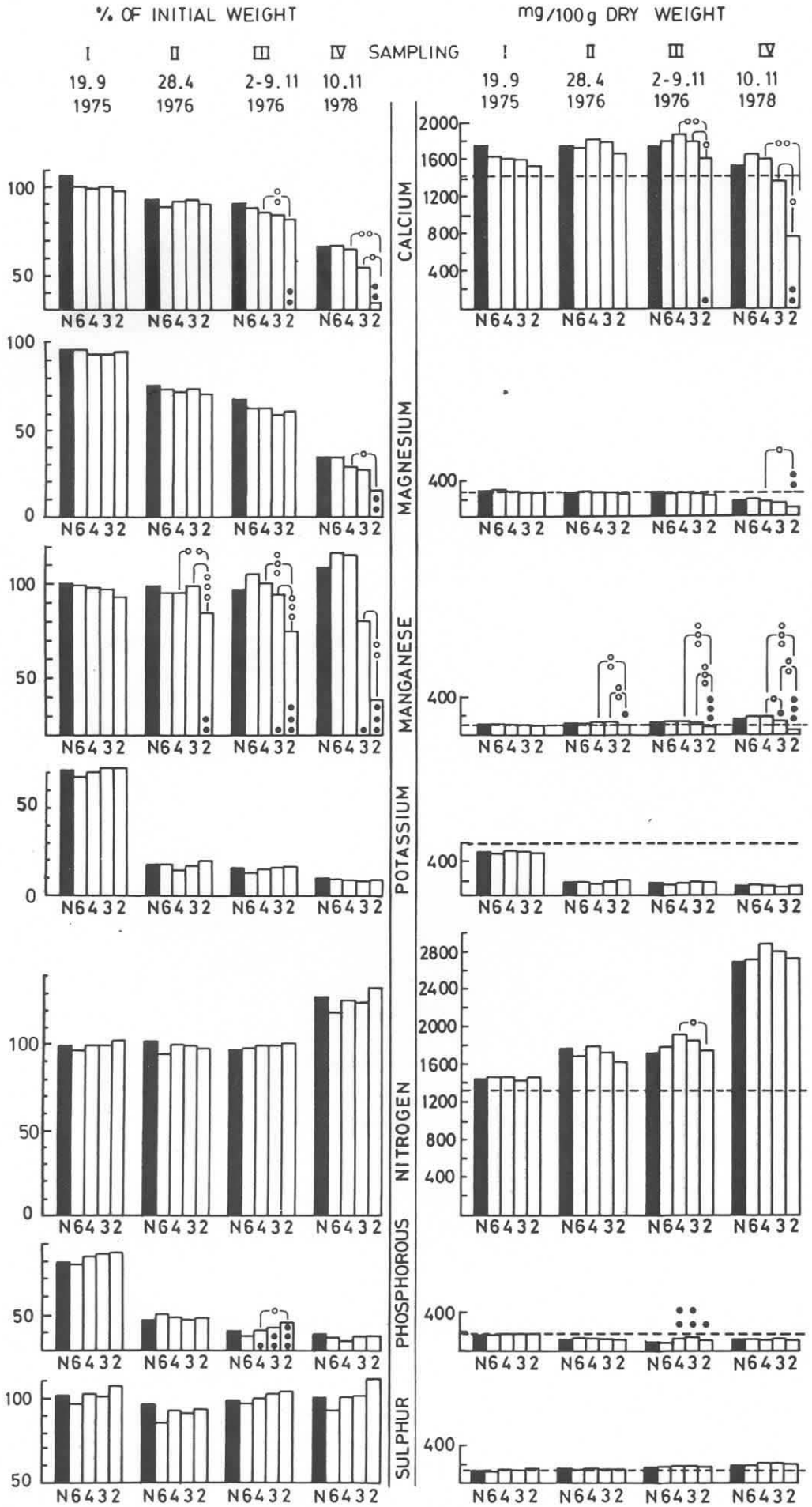
3.3. Buffering capacity of leaves

In addition to the effect of acidification on decomposition rate and the chemistry of the leaves, the microenvironment in the litter bags depends on the leaves' ability to neutralize the acid water as it moves vertically through the bag. The neutralization ability of the leaves may be important for microflora and microfauna, which come into direct contact with the acidified water.

To check the buffering capacity of decomposing birch leaves, a total of 40 mm of diluted sulphuric acid of pH 2.1 was slowly dripped on litter bags over a period of one hour, and pH was measured periodically in the water collected below the bags. This rate of watering corresponded to the field experiment, but in the laboratory experiment the 10 mm of water was added over a few minutes. The size of bags and decomposition phase of the leaves were that of "late phase" leaves at the start of the acidification experiment. The structure of the leaves was still intact. To see how fast buffering was realized within the bags, acidified water was also percolated through half bags, where the lower part had been cut away. Measurements were made after 5 mm, 10 mm, 20 mm, 30 mm and 40 mm of "rain", and the observed values are the mean of three bags.

The water collected under intact bags had the following pH values: 2.86 (after 5 mm "rain"), 2.73 (10 mm), 2.66 (20 mm), 2.49 (30 mm) and 2.50 (40 mm). This means that the organisms surviving in this microenvironment periodically must withstand direct contact with diluted sulphuric acid with a pH well below 3. The half bags gave similar values, indicating that the actual buffering is finished very soon, in the top of the leaf layers.

Fig. 3. Changes in chemical composition of birch leaves in litter bags (laid out 28. 7. 1975). Black columns: Non-watered plots. Figures below columns indicate pH in artificial rain. Horizontal broken lines show the concentration of each element at the beginning. Note that scales in the left half may start at different levels. Filled circles indicate significant effects of acidification, compared to control-watered plots (given "rain" of pH 6). Other differences between treatments are shown by open circles. One circle = $P \leq 0.05$; two circles = $P \leq 0.01$; three circles = $P \leq 0.001$.


% OF INITIAL WEIGHT
mg/100g DRY WEIGHT
I II III IV SAMPLING
19.9 1975
28.4 1976
2-9.11 1976
10.11 1978
CALCIUM
MAGNESIUM
MANGANESE
POTASSIUM
NITROGEN
PHOSPHOROUS
SULPHUR
N6432

4. Discussion

4.1. Decomposition rate

4.1.1. Effect of season and decomposition phase

The marked dry weight reduction observed in the field during low temperatures in late autumn and in winter was probably due mainly to leaching. Especially at snow melt, large amounts of water pass through the bags. Also Gosz et al. (1973) found considerable dry weight losses in leaves of yellow birch (*Betula allegheniensis* Britt) during the first winter. McBrayer & Cromack (1980) found that breakdown of *Quercus* leaves occurred even under a snow cover, although rather slowly. Bleak (1970) studied winter decomposition of two grasses and two broadleaved forbs and found that 30—51 % of the dry weight was lost while the litter was covered by snow. Sheltered samples indicated that only a smaller part of the observed weight loss was due to leaching. In that type of litter, decomposition by the microflora is apparently an important factor also in winter.

The summer of 1976 was unusually dry, and periods in the two succeeding summers were also dryer than normal (Fig. 1). This fact, and the general dryness of such sun exposed clear cut areas, must account for the very low decomposition rates during the two and a half years after the initial leaching period. Other factors deviating from natural conditions were: the thickness of the leaf layer (3 cm), the vertical orientation of the leaves, the insertion of the bag into the 0-layer, and the early deposition of the leaves (before natural leaf fall time). Therefore, the observed weight loss rate should be taken only as approximate, even for the relevant habitat. The contrasting decomposition rate under greenhouse conditions demonstrates very well the effect of microclimate for decomposition processes. The greenhouse experiment illustrates that decomposition rate is slowed down after the leaching period ("late" versus "early" phase).

4.1.2. Effect of acidification

Both field and greenhouse experiments indicated that application of *p*H 2-water reduced the decomposition rate. These results are supported by other decomposition studies under the influence of diluted sulphuric acid. Bååth et al. (1980) studied the decomposition of Scots pine root and needle litter in a field experiment where the soil had previously been subjected to very high concentrations of sulphuric acid over six years (50 or 150 kg H_2SO_4 ha^{-1} $year^{-1}$, applied as *p*H 1.1). Root litter placed for one year in the Of/Oh layer in the most acidified plots decomposed somewhat slower than in untreated plots, and the same was observed for needle litter placed on the litter surface. The differences were, however, not significant. After two years, the decomposition of needle litter proved to be significantly slower at both levels of acidification. The authors considered that the lowered decomposition rate in buried root litter was due to reduced microbial activity in soil. However, they could not explain the reduced decomposition rate in the needle litter. No acid had been distributed on the needle litter samples, and the litter bags had been placed on the newly fallen autumn litter, not in direct contact with the acidified soil.

Hågvar & Abrahamsen (1980) showed that the decomposition rate of raw humus was significantly lowered when the *p*H was reduced from 4.5 to values between 2.9 and 3.5. Tamm et al. (1977) found that the addition of powdered sulphur or sulphuric acid to incubated raw humus reduced the CO_2 production. They concluded that the treatments had reduced the activity of microorganisms.

An experiment with Norway spruce needles in laboratory lysimeters indicated that application of dilute sulphuric acid of *p*H 3 and *p*H 2 might increase decomposition rate in the early phase. Later, however, when the needles consisted mainly of less degradable substances, the same applications seemed to retard the decomposition. The conclusions were supported by parallel respiration studies (Hovland et al. 1980). Also Roberts et al. (1980) observed increased decomposition rate in the early decomposition phase of pine needles in the field by application of *p*H 3.1- and *p*H 2.7-water. However, their study did not include later phases of decomposition.

Hovland & Abrahamsen (1976) studied the influence of artificial acid "rain" on decomposition of cellulose sheets and small pieces of aspen wood (*Populus tremula* L.), placed on the litter in three coniferous forest sites. The only significant result was a reduced decomposition rate of cellulose in one site, after application of *p*H 2.5-water.

In the O-layer surrounding the field litter bags in the present study, Bååth et al. (1979) found that the strongest acidification (*p*H 2) had reduced total soil respiration, the abundance of FDA-active bacteria, and also mean bacterial size. No significant changes were, however, observed in FDA-active fungal biomass, or in total length of hyphae. If microbial reactions were similar in litter bags, reduced bacterial activity may be responsible for the reduced decomposition rate of birch leaves.

4.2. Leaf chemistry

4.2.1. Effect of season and decomposition phase

A marked weight loss due to leaching in the first weeks is typical for deciduous leaf litter. Much K, and also Mg, is usually lost during this initial phase (Bocock et al. 1960, Crossley & Witkamp 1964, Attiwaill 1968, Burges 1967, Gosz et al. 1973, Howard & Howard 1974). In the present field experiment, however, Mg was rather well retained in this phase, while as much as 20 % of P was lost in the untreated samples. The leaching was most pronounced during the winter period, when more than 50 % of K, 30 % of P and 20 % of Mg was lost. Further loss of K and P during the next 2.5 years was small, while Mg was continuously lost down to 35 % of the initial value.

The great loss of K during winter may have connection with destruction of cells by ice formation within the leaves. In a lysimeter experiment with soil monoliths including herb vegetation, Abrahamsen & Stuanes (pers. comm.) found increased leaching of K after a frost period.

The loss of K and Mg in leaf litter of yellow birch was also large during the first winter, while the total amount was relatively unchanged during the following snow-free season (Gosz et al. 1973). Contrary to the present experiment, however, they found that P was retained and even increased in total amount during the first year of decomposition. This di ference may be explained by comparing the N : P ratio in the two experiments after approximately one year. This ratio was 16.5 : 1 for yellow birch after twelve months and 17.3 : 1 in the present experiment after fifteen months, which are very similar values. Probably the original P content was higher than needed by the microflora, which led to leaching, while leaching later was reduced due to immobilization. N has obviously been a limiting factor for microbial populations during the whole three-year period, causing immobilization and full retention from the beginning. After the first year, the total amount increased due to absorption from the surroundings (colonising organism, precipitation, green leaf litter, N-fixation). Gosz et al. (1973) found increased total amounts of N in leaf litter of yellow birch, beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum* Marsh.). Immobilization of N led to a marked increase in concentration during decomposition in the present study, a phenomenon well known from both terrestrial and aquatic litter (Bocock 1963, Matthews & Kowalczewski 1969, Gosz et al. 1973, Howard & Howard 1974).

In the present experiment, Mn behaved similar to N, with a certain increase in total amount and a marked increase in concentration. In yellow birch leaf litter (Gosz et al. 1973), there was a certain loss of Mn through leaching during autumn and winter. Later the leaching stopped, probably by conversion to insoluble MnO_2 by microorganisms (Alexander 1967), and the concentration gradually increased as in the present study.

The total amount of S was practically unchanged in non-watered bags after three years. The yearly deposition of this element through precipitation is large per bag (about 2.5 mg), compared to the initial amount (8.4 mg). As the total amount of S did not increase significantly even in strongly acidified bags, the leaching rate of this element must have been equal to the deposition rate, irrespective of the amounts received. Obviously, there has been no need for the microflora in the relevant litter to increase the original amount of this ele-

ment. Gosz et al. (1973), however, found that the total amount of S in leaves of yellow birch was accumulated from precipitation during decomposition. They suggested that the quantity of P available to microorganisms affected the accumulation of S in decomposing tissue.

Calcium occurs mainly in structural components of leaves. Several studies have shown that it is often a good correlation between Ca loss and dry weight loss (ATTIWILL 1968, THOMAS 1969, Gosz et al. 1973, VAN CLEVE & NOONAN 1975, JONASSON 1979, STAAF 1979). In the present experiment, Ca was lost somewhat slower than the dry weight, resulting in a certain increase in concentration.

The greenhouse experiment cannot be directly compared with the field study, as climatic conditions were quite different. However, the same main trends as pointed out above were found in the control samples (Tab. 2, *p*H 5.3). K, P and Mg were effectively leached, the total amount of N increased (in the "early" phase), and S and Mn were rather well retained. Increased concentrations were recorded for N, S, Mn and Ca, but also for Mg during the early phase.

The observed rise in leaf *p*H during the leaching phase in both experiments and relatively constant values during the subsequent decomposition is in accordance with observations by NYKVIST (1961) (leaves of *Betula verrucosa*) and SJØRS (1959) (*B. verrucosa* and several other deciduous trees). Probably, the increased *p*H is due to leaching of acidic solutes (e.g. organic acids) in the cell sap (WILLIAMS & GRAY 1974).

4.2.2. Effect of acidification

The present effects of acidification on the leaching rate of certain elements are supported by other experiments. Increased leaching of Ca, Mg and Mn by application of dilute sulphuric acid has been found in raw humus (HÅGVAR & ABRAHAMSEN 1980), in decomposing needles of spruce (HOVLAND et al. 1980) and in lysimeter with indisturbed soil monoliths of iron podzol (Typic Udipsamment) (ABRAHAMSEN et al. 1976b, ABRAHAMSEN 1980a, b). In decomposing spruce needles, HOVLAND et al. (1980) found that acidification first reduced leaching of P and then increased it. This is in accordance with the present observations. After one year, the content of P was highest in the acidified samples, but not after three years. The same trend can be found in the strongest treatment in the laboratory experiment, comparing the "early" and "late" phases. As in birch leaves, *p*H in decomposing spruce needles was reduced by artificial acidification (HOVLAND et al. 1980).

5. Final remarks

The present results are in accordance with other studies on the effect of artificial acidification on litter and soil. The general picture is reduced decomposition rate and microfloral activity, and increased leaching of metal cations such as Ca^{2+}, Mg^{2+} and Mn^{2+}. However, these effects have been observed only by application of much stronger acid than found in the, "natural" acid rain and snow. High concentrations (e.g. *p*H 2) are injurious to vegetation, and compared to "natural" acid rain increased acidity of the artificial "rain" will also increase the discquilibrium between the solid phase and water phase in soil. The effects of short-term application of strong acids are therefore not comparable to the long-term effects of weaker acids. A low number of replications implies that only large effects will show up as statistically significant, however. Furthermore, long-term experiments (10—20 years) on the effect of weak acidification on litter and soil do not exist. At the moment, the possible effects of long-term acid precipitation on soil processes are poorly understood.

However, according to ABRAHAMSEN (1980a), results from field experiments with less acidic treatments indicate that the present acidity of precipitation has increased the leaching of Ca and Mg especially and reduced soil *p*H and base saturation. Likewise, field surveys concerning the chemistry of the organic layer in Swedish coniferous forests in 1961/63 and 1971/73 strongly indicated decreasing contents of exchangable Ca^{2+}, Mg^{2+} and K^{+} during this period (TROEDSSON 1980).

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7. Summary · Résumé

Leaves of birch (mixture of *Betula pubescens* Ehrh. and *B. verrucosa* Ehrh.) were kept in litter bags under small *B. verrucosa* plants (0.5—1 m) on a previously clear-cut area. As much as 13 % dry weight was lost during the first winter, when the ground was mostly covered by snow. After over three years, however, dry weight loss was not more than 37 %. A corresponding weight loss occurred during only three months under warm and moist conditions in a similar greenhouse experiment. In the field, elements were lost at different rates (in % of initial weight): K > P > Mg > Ca > S > Mn > N. The total amount of N increased in litter bags after 1—3 years. Litter bags both in the field and in a greenhouse were acidified with artificial acid "rain" (diluted sulphuric acid) of *p*H 4, 3 and 2. Application of ground water (*p*H 6) in the field and simulated "rain" (*p*H 5.3) in the greenhouse were considered as controls. The strongest acidification (*p*H 2) resulted in significantly lower decomposition rate in the "early" decompcsition phase in the greenhouse. Corresponding tendencies were observed in a "late" decomposition phase in the greenhouse and in the field experiment. Application of *p*H 2-water also increased the leaching rate of Ca, Mg and Mn in both field and greenhouse experiments. Watering with a weaker acid (*p*H 3) did not affect decomposition rate or leaf chemistry significantly. except for increased leaching of Mn in the field. No effects could be observed from the *p*H 4-treatment,

Décomposition des feuilles de bouleau: pertes de poids sec et changements chimiques; effects de pluie acide artificielle.

Des feuilles (mélange de *Betula pubescens* Ehrh. et *B. verrucosa* Ehrh.) ont été gardées dans des sacs de nylon sous de petites plantes de *B. verrucosa* (0.5—1 m) sur une surface déjà déboisée. Pendant le premier hiver, 13 % de poids sec ont été perdus alors que la plupart du temps la terre était couverte de neige. Après trois ans, les pertes de poids sec n'étaient que de 37 %. Des pertes de poids équivalentes sont déjà atteintes après seulement trois mois dans des circonstances chaudes et humides au cours d'un essai en serre chaude. En nature, les éléments minéraux ont été perdus à des vitesses différentes (exprimé en % du poids initial): K > P > Mg > Ca > S > Mn > N. Après 1—3 ans la valeur totale de N a augmenté dans les sacs de nylon. Des sacs de nylon tant dans les serres qu'en nature ont été acidifiés par de la pluie acide artificielle (acide sulfurique dilué) de *p*H 4, 3 et 2. Des applications d'eaux souterraines (*p*H 6) en plein champ et de la pluie simulée (*p*H 5.3) dans les serres ont servi de contrôle. L'acidification la plus forte (*p*H 2) a eu comme résultat une valeur de décomposition significativement plus faible que le stade "précédent" de la décomposition dans la serre. Des tendances analogues ont été distinguées au stade de décomposition "récent" dans la serre et dans les expériences de terrain. L'application d'eau à *p*H 2 a également augmenté la valeur du lessivage du Ca, Mg et Mn tant pour les expériences en serre qu'en plein champ. L'arrosage par un acide plus faible (*p*H 3) n'a pas eu d'effet significatif sur la valeur de la décomposition ou sur la composition chimique des feuilles, à l'exception d'une augmentation du lessivage de Mn en nature. Aucun effet n'a été mis en évidence au traitement de *p*H 4.

8. Literature

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